UNCLASSIFIED

AD NUMBER
AD032076
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; MAR 1954. Other requests shall be referred to Ballistic Research Laboratories, Aberdeen Proving Ground, MD.**
AUTHORITY
BRL ltr dtd 22 Apr 1981

THIS PAGE IS UNCLASSIFIED

BRL

TECHNICAL NOTE No. 887

Shock-Wave Yaw For $9\frac{1}{2}^{\circ}$ Semi-Apex Cone

EUGENE D. BOYER

DEPARTMENT OF THE ARMY PROJECT No. 503-03-001
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0108

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

search Laboratories Technical Note is designed for use with-
or for issuing available information, when the occasion

er are of the nature of advance information and may
revised.

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

TECHNICAL NOTE NO. 887

March 1954

SHOCK-WAVE YAW FOR 9 1/2° SEMI-APEX CONE

Eugene D. Boyer

Department of the Army Project No. 503-03-001
Ordnance Research and Development Project No. TB3-0108

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

BALLISTIC RESEARCH LABORATORIES

Technical Note No. 887

EDBoyer/ddh
Aberdeen Proving Ground, Md.
March 1954

SHOCK-WAVE YAW FOR 9 1/2° SEMI-APEX CONE

ABSTRACT

The semi-apex angle of the shock-wave and the ratio of the shock-wave to the yaw of a projectile for small yaw is theoretically predicted by A. H. Stone. Experimental verification of the theory was obtained from cones and cone cylinders fired in the Free Flight Aerodynamics Range.

INTRODUCTION

If the direction of motion of a cone flying through air does not coincide with its axis of symmetry it is said to have yaw. For a yawing cone flying at supersonic speeds the resulting shock-wave will also have yaw. (See Fig. 1) The ratio of this shock-wave yaw to the yaw of the cone can be predicted by Stone's theory. [1] [1] The semi-apex angle of the shock-wave can also be predicted by this theory. Empirical values were obtained by measuring these quantities from spark photographs taken in B.R.L.'s small spark range.[2] No significant difference was observed between the experimental and theoretical values. This, in essence, is a verification of the theory.[3] The data included in this report supplement the B.R.L. data in Stone's work [1] which he uses to verify his theory.

SHOCK-WAVE YAW FOR 9 1/2^{o} SEMI-APEX CONE

The theoretical values for the ratio of the shock-wave yaw to the yaw of the cone as predicted by A. H. Stone are obtained directly from Kopal's tables. [3] , [4]. In order to determine these values for a cone, semi-apex angle θ_S of 9 1/2^{o}, we must first determine the surface velocity component u_s, which is tabulated in [3] in terms of the Mach number M. Knowing u_s, we can then obtain the shock to cone yaw ratio, δ/ϵ , by two-way linear interpolation. [4] . Figure 2 shows the predicted behaviour of the ratio δ/ϵ for various Mach numbers.

The empirical values were obtained from measurements of spark photographs taken in the small spark range. A number of rounds with different Mach numbers were selected for a distribution of points on the δ/ϵ vs M curve. Since the change in M is less than .16 through the range, each round is considered to have a constant Mach number. The yaws were measured only in one plane, vertical or horizontal. Only those stations were selected for which the yaw in one plane was very small, less than 1/2^{o}, and the yaw in the measured plane was fairly large, at least six times as great.

The projected angular positions δ^* and ϵ^* were measured on a grid. From these measured angles the true yaw is obtained. [5]

Since we are considering a body of revolution it is reasonable to assume that for zero yaw the yaw of the shock-wave is also zero. The ratio of the two yaws can then be determined by fitting the function $\delta = b\epsilon$, by least squares, to the yaw angle data, Fig. 3. These values along with the theoretical values are seen in Figure 2 plotted against Mach number. The agreement is good with the differences of the experimental and theoretical values being less than the statistical error of the experimental values. This good agreement might be considered as a verification of Stone's theory.

---

[1]The numbers in the brackets refer to the Reference number.

[2]The dynamic properties of these cone models are described in [6].

[3]Wind tunnel measurements [2] have also verified Stone's Theory in this regard.

SHOCK-WAVE ANGLE

The theoretical values for the semi-apex angle θ_W of the shock-wave are obtained directly from Kopal's tables [3] in terms of Mach number.

The experimental values are obtained from measurements taken from the spark photographs. From the plot of the observed and theoretical values vs Mach number in Figure 4 it can be seen that the agreement also is good.

Eugene D. Boyer
EUGENE D. BOYER

REFERENCES

1. Stone, A. H., On Supersonic Flow Past A Slightly Yawing Cone, Journal of Mathematics and Physics, 30 (1952).

2. Cronvich, L. L., Results of Experimental Studies of Pressure Distributions On Cones At Supersonic Velocities, APL/JHU TG-91, (1950).

3. Kopal, Z., Tables Of Supersonic Flow Around Cones, M.I.T. Technical Report No. 1, (1947).

4. Kopal, Z., Tables Of Supersonic Flow Around Cones, M.I.T. Technical Report No. 3, (1947).

5. Murphy, C. H., Data Reduction For The Free Flight Ranges, BRL Report 900 (1954).

6. Schmidt, L. E., The Dynamic Properties Of Pure Cones And Cone Cylinders BRLM 759, (1954).

TABLE OF SYMBOLS

M	Mach Number
b	Slope of line where $\delta = b\epsilon$
u_s	Surface velocity
θ_S	Semi-apex angle of cone
θ_W	Semi-apex angle of shock-wave
δ	Yaw of shock-wave
ϵ	Yaw of cone
δ^*	Projected angle of shock-wave
ϵ^*	Projected angle of cone
σ_b	Standard error in slope

YAWING CONE

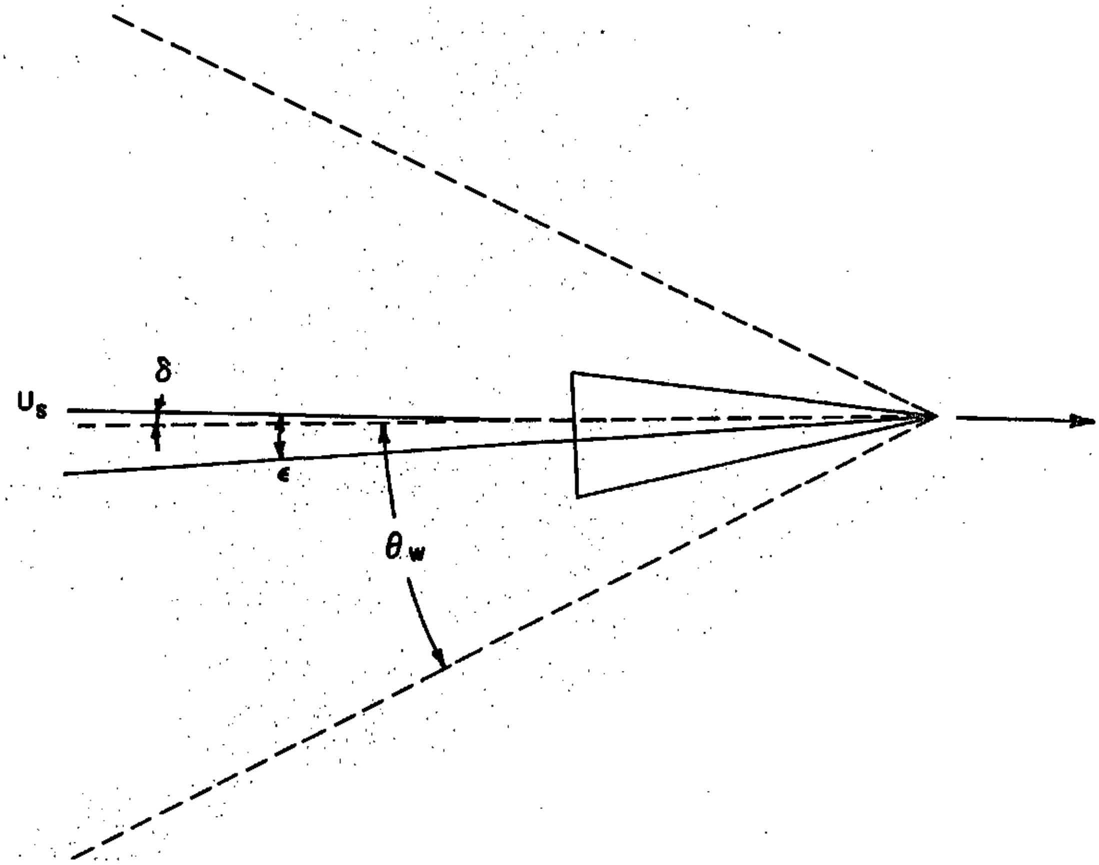
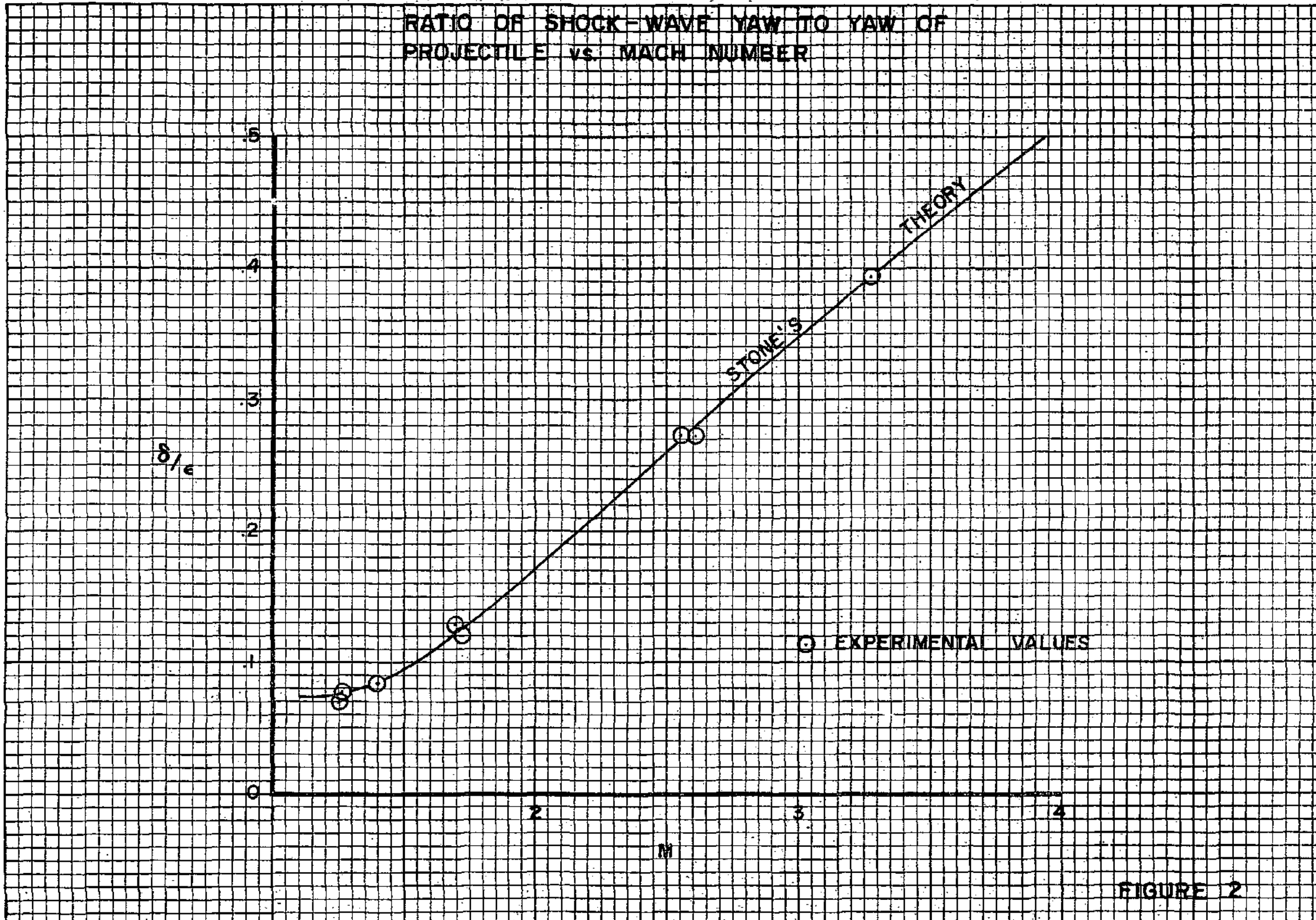


FIGURE I



RATIO OF SHOCK-WAVE YAW TO YAW OF PROJECTILE vs. MACH NUMBER

FIGURE 2

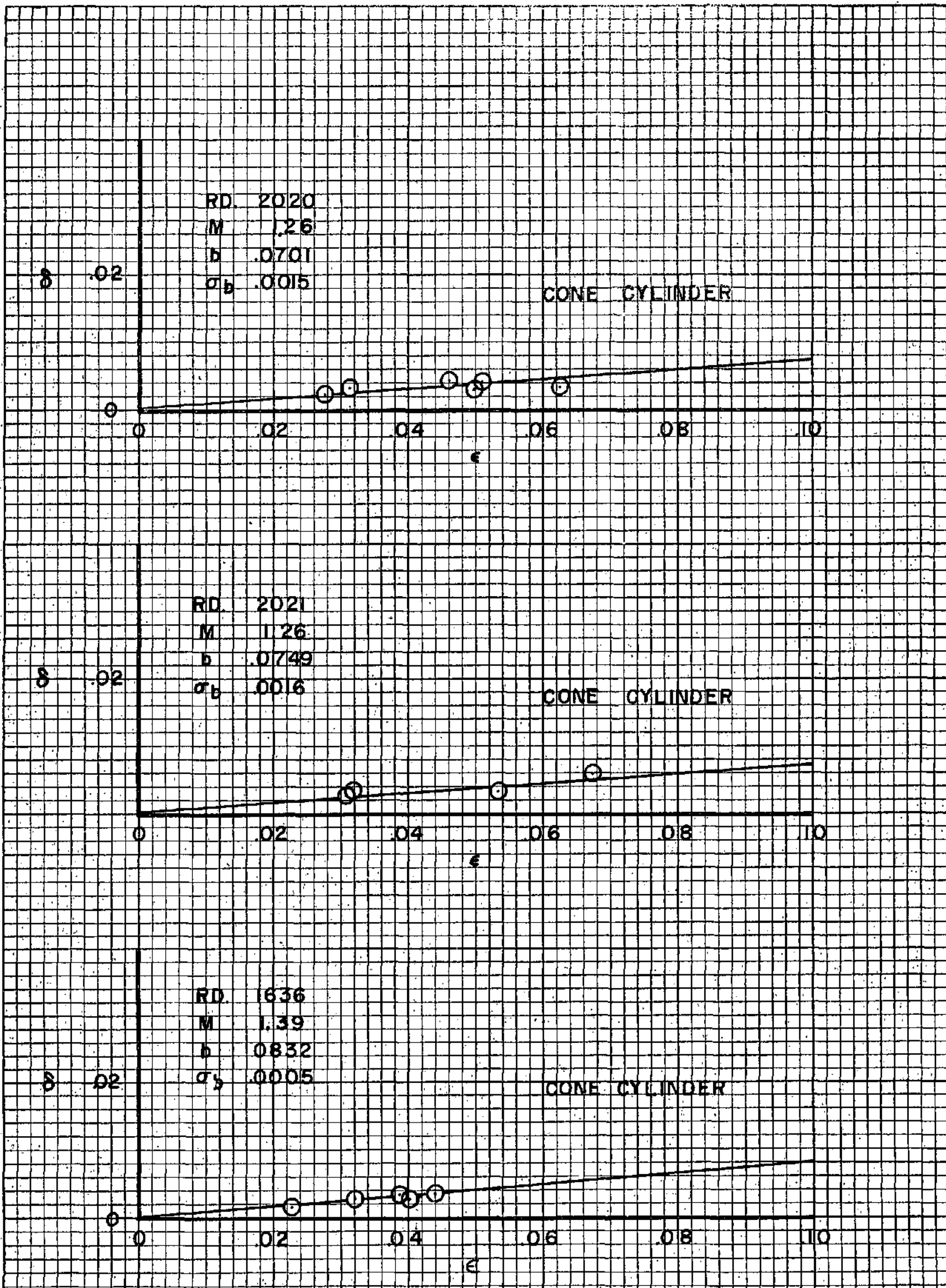

RD. 2020
M 1.26
b .0701
σb .0015
CONE CYLINDER
δ
.02
0
.02
.04
.06
.08
.10
ϵ
RD. 2021
M 1.26
b .0749
σb .0016
CONE CYLINDER
δ
.02
0
.02
.04
.06
.08
.10
ϵ
RD. 1636
M 1.39
b .0832
σb .0005
CONE CYLINDER
δ
.02
0
0
.02
.04
.06
.08
.10
ϵ

FIGURE 3 A

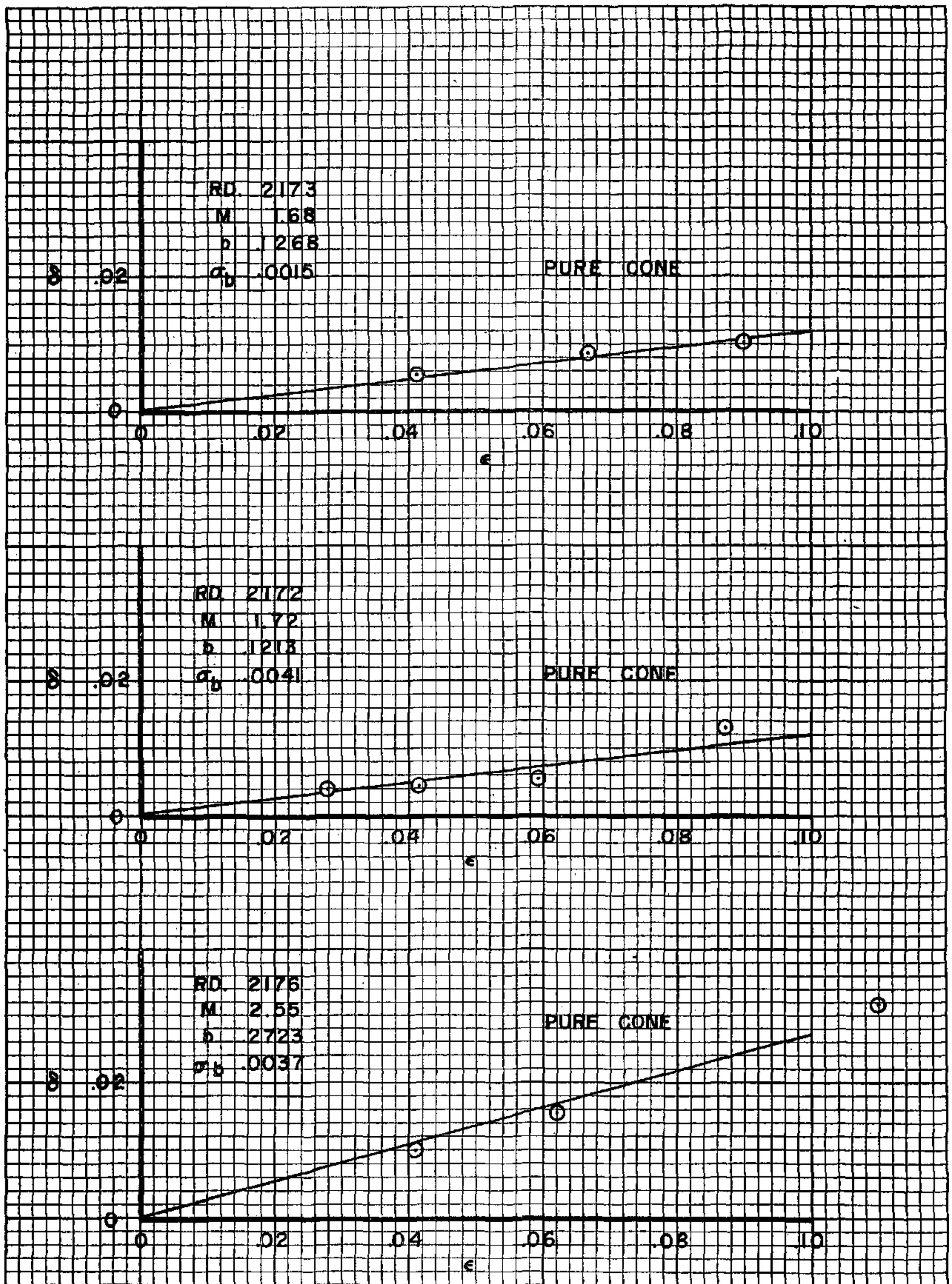

RD. 2173
M 1.68
b .1268
σ_b .0015
PURE CONE
δ .02
0
0
.02
.04
.06
.08
.10
ε
RD. 2172
M 1.72
b .1213
σ_b .0041
PURE CONE
δ .02
0
0
.02
.04
.06
.08
.10
ε
RD. 2176
M 2.55
b .2723
σ_b .0037
PURE CONE
δ .02
0
0
.02
.04
.06
.08
.10
ε

FIGURE 3-B

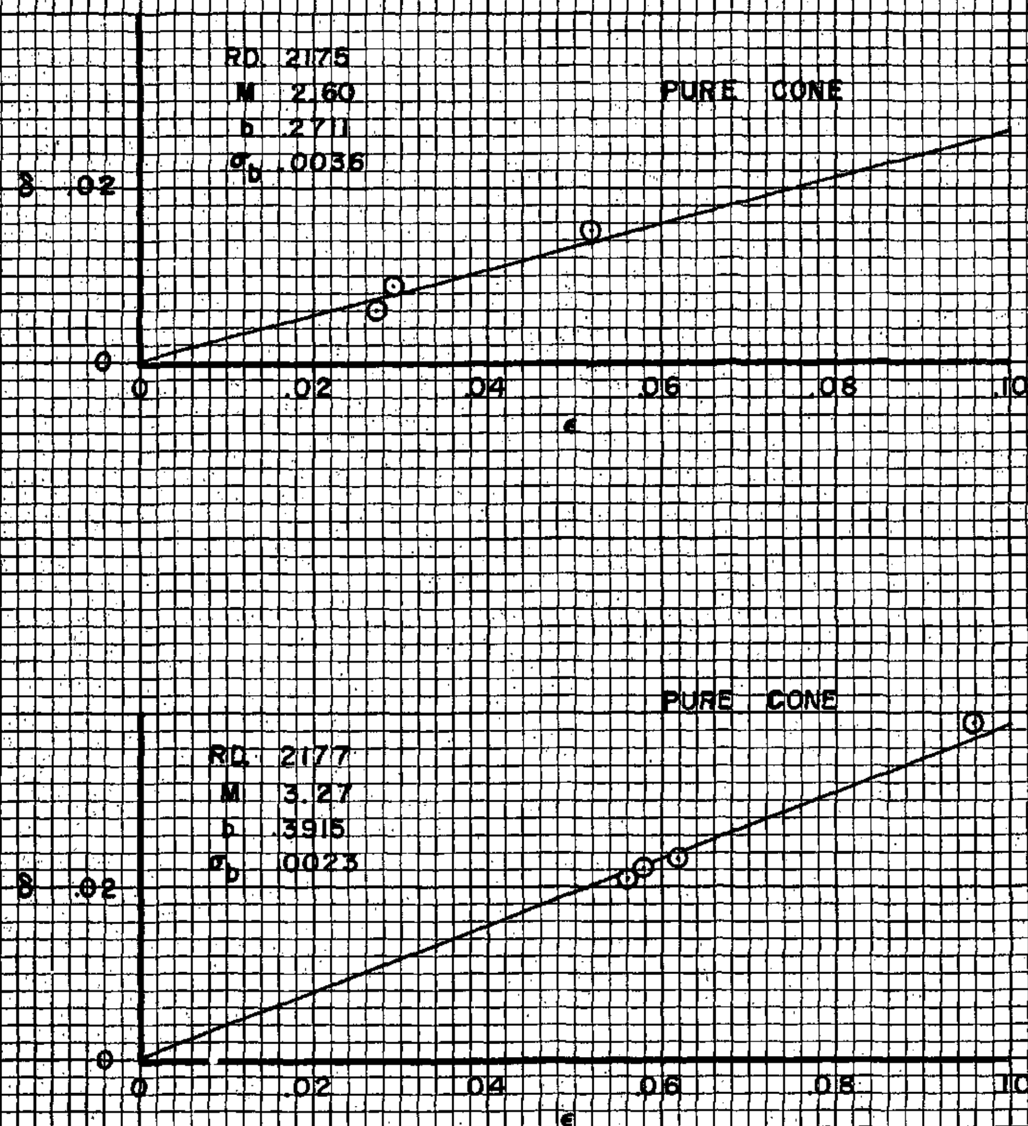

RD 2175
M 2.60
b .2711
σ_b .0036
PURE CONE
δ .02
0
0
.02
.04
.06
.08
.10
ε
RD 2177
M 3.27
b .3915
σ_b .0023
PURE CONE
δ .02
0
0
.02
.04
.06
.08
.10
ε

FIGURE 3-C

SEMI-APEX ANGLE OF SHOCK WAVE
vs.
MACH NUMBER

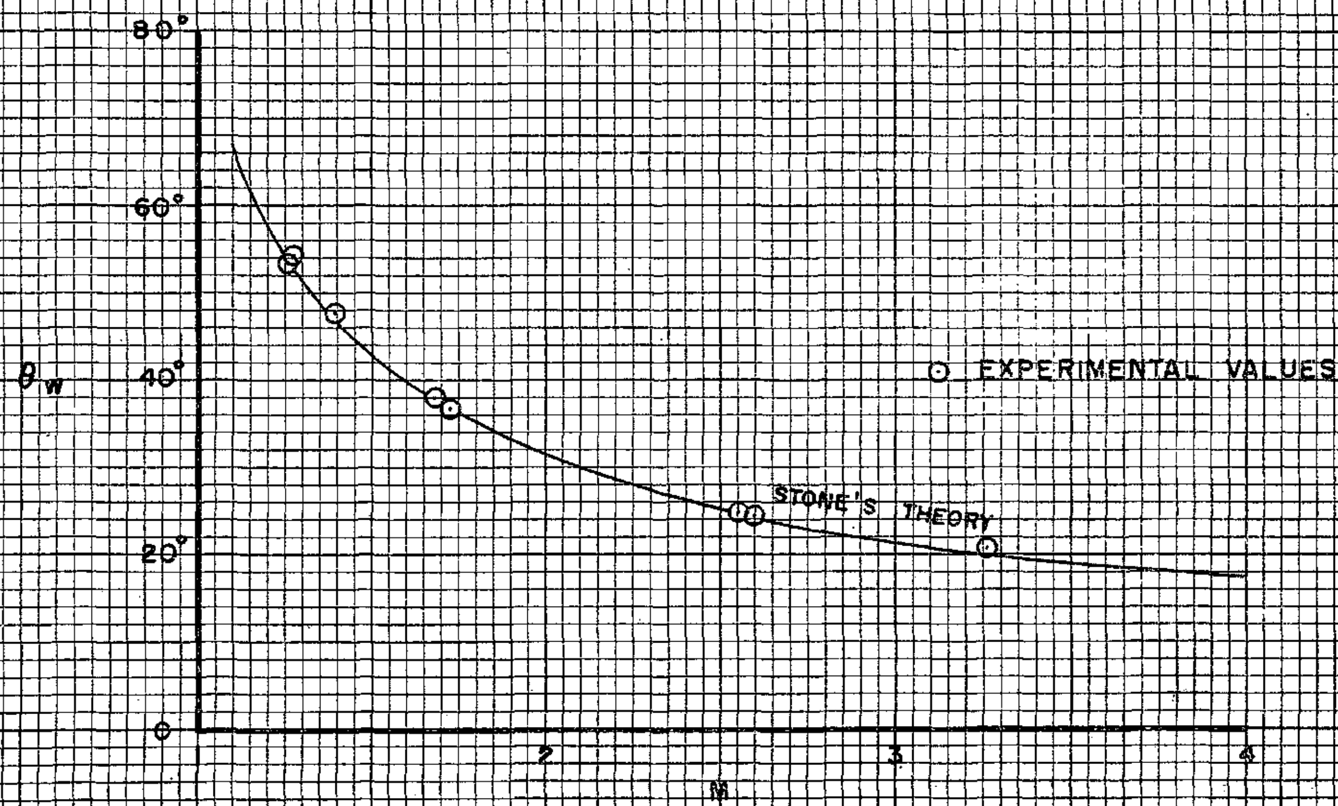


FIGURE 4

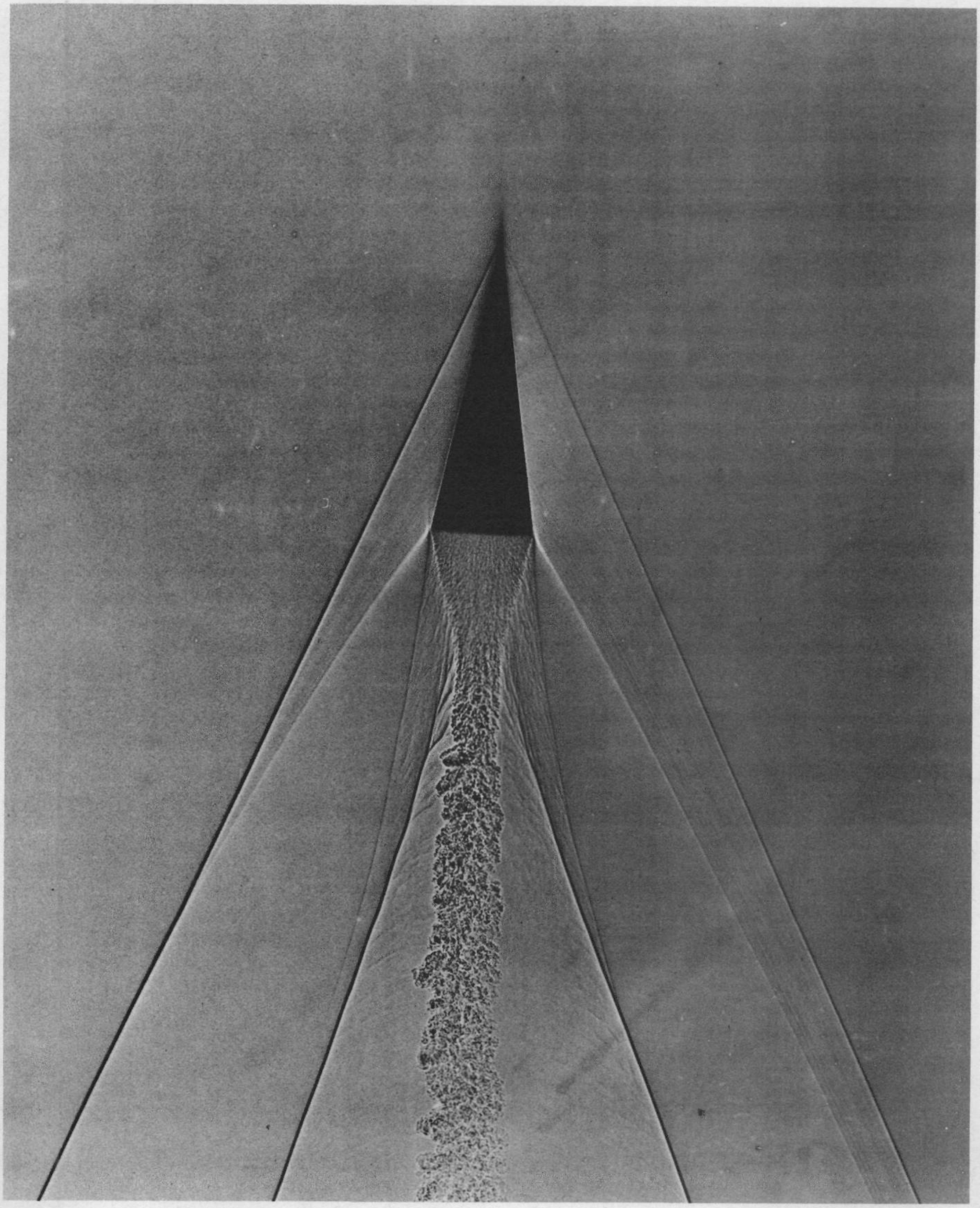


FIG. 5

SHADOW GRAPH PURE CONE

DISTRIBUTION LIST

No. of Copies	Organization
4	Chief of Ordnance Department of the Army Washington 25, D. C. Attn: ORDTB - Bal Sec
10	British - ORDTB for distribution W.F. Cope - Ministry of Supply
4	Canadian Joint Staff - ORDTB for distribution
4	Chief, Bureau of Ordnance Department of the Navy Washington 25, D. C. Attn: Re3
4	ASTIA Reference Center Technical Information Division Library of Congress Washington 25, D. C.
3	Commander Naval Ordnance Laboratory White Oak Silver Spring, Maryland Attn: Mr. Nestingen Dr. May Dr. Kursweg
1	Commanding Officer and Director David W. Taylor Model Basin Washington 7, D. C. Attn: Aerodynamics Laboratory
2	Commander Naval Ordnance Test Station Inyokern P. O. China Lake, California Attn: Technical Library W. R. Haseltine
1	Commander Air Research and Development Command P. O. Box 1395 Baltimore 3, Maryland Attn: RDDAS
3	Director National Advisory Committee for Aeronautics 1724 F Street, N. W. Washington 25, D. C. Attn: Division Research Information
1	Director National Advisory Committee for Aeronautics Ames Laboratory Moffett Field, California Attn: Dr. A. C. Charters
5	Director Armed Services Technical Information Agency Document Service Center Knott Building, Dayton 2, Ohio Attn: DSC - SA
1	Professor George Carrier Division of Applied Sciences Harvard University Cambridge 38, Massachusetts
1	Professor J. W. Cell North Carolina State College Raleigh, North Carolina
1	Professor Francis H. Clauser Department of Aeronautics Johns Hopkins University Baltimore 18, Maryland
1	Professor Edward J. McShane Department of Mathematics University of Virginia Charlottesville, Virginia
1	Dr. C. B. Millikan Guggenheim Aeronautical Laboratory California Institute of Technology Pasadena, California
1	Dr. L. H. Thomas Watson Scientific Computing Labotatory 612 West 116th Street New York 27, New York